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The Limited Entry Prawn Fisheries of Western Australia: Research and Management

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BY

B. K. BOWEN and D. A. HANCOCK

1982

WESTERN AUSTRALIAN
MARINE RESEARCH LABORATORIES
DEPARTMENT OF FISHERIES AND WILDLIFE
PERTH, WESTERN AUSTRALIA

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In Exmouth Gulf, 15 licenses were issued in 1965, then increased to 17 in 1967 and again to 20 (+ 3 standby vessels) for 1970 and 1971. The standby arrangement was phased out in 1972 and the number of full licenses increased to 22 for the period 1972 to 1978. For the current triennium, 1979–81, one provisional license has been issued bringing the total to 23. This license will be reviewed at the end of the 1981 season.

During the early years of the fishery, vessels were exclusively converted rock lobster boats, and it was not until the early 1970's that these were replaced by specifically designed prawn trawlers of approximately 19 m overall length (Penn and Hall, in prep). Since 1979 four vessels have been replaced with larger vessels which qualify for the shipbuilding subsidy (Penn and Hall, in prep.).

Nickol Bay

Catch statistics for Nickol Bay are given in Table 4. Up to and including 1977, catches were based on banana prawns, but from 1978 brown tiger prawns, with smaller quantities of western king prawns, from more distant grounds have assumed importance. Catches have been very variable, with a ten year range of 0·02 to 0·45 m kg and an average of 0·16.

Boat licenses in this fishery were limited in 1971 to 13. Since 1975 there have been 16 licensed vessels, though during 1980 only 13 boats were fishing at any one time. Fishing commenced in 1966 with one vessel followed by numbers ranging from 7 to 22 fishing in any one month during the years before limited entry.

III SOURCES OF DATA

Commercial fisheries production monthly return—it is mandatory for all licensed professional fishermen to provide monthly returns, which are collected by the Western Australian Department of Fisheries and Wildlife under the Fisheries Act 1905 and processed by the Australian Bureau of Statistics. Prawn fishermen are required to list, separately for each species of prawn trawled, the area fished (by 1° statistical blocks), the average number of shots per day, the average number of hours fished per day, the number of days searching (relevant only to banana prawns) and fishing and total weight landed during the month, in the categories of "whole" or "headed".

Prawn processors' monthly return—it is mandatory for prawn processors to provide details of their suppliers (home anchorage, registered boat number, live weight supplied by them) and quantities sold.

Research logbooks—commencing in 1963, each prawn vessel skipper is expected to complete a daily research logsheet giving details of net type and specifications, fishing position at the start and finish of the day's fishing, together with, for each shot, the area listed (by 1/6° statistical blocks), named trawl ground, start time and duration of haul, depth at start and end, and weight of catch by species. An innovation in recent years has been to record the main fishing preference (intention to fish) for the day, by species of prawn, for scallops or with "no preference". These records proved to be less useful for analysis than those of habitat preference. The research logsheet scheme (Hancock, 1973) has continued to provide essential data for management. The ingredients for the success of this system (Hancock, 1974) have remained as:—

(a) Sustained personal contact with the fishermen and early verbal validation of anomalous records.

(b) Computer validation for spurious log book entries.

(c) Validation between log books and fishermen's and processors' returns available.

(d) Rapid availability of data for management.

(e) Prompt feedback of information to participants.

Rapid availability of data (d) is of considerable importance to management by limited entry and it will be noted that assessment can here be made to include fully analysed data for the last completed prawn season (1980), which would not, by necessity, be possible from available official statistics.

Factory measurements—commenced in 1963 to provide size frequency measurements of prawns landed from each fishing region in Shark Bay, which are required for weight to number conversions.

Monitoring the stocks—from 1974 to 1976 annual surveys were made by research vessel (Penn, pers. comm.) of prawn distribution and abundance in Shark Bay. In 1978, 1980 and 1981 these surveys were extended to include scallop fishing grounds. Similar surveys of the Exmouth fishery were carried out in 1975, 1976 and 1977. In addition, from 1978, the growth of juvenile prawns in Shark Bay has been measured aboard commercial and research vessels to monitor the effects of closure of an extended nursery area on the size of prawns entering the fishery and to determine an appropriate date for opening the extended nursery area to fishing.

Economic studies—conducted periodically and results published by the Commonwealth Department of Primary Industry (Anon, 1970, 1975; Meany, 1979; Owen, 1981).

Research programmes—continuing and past studies have included factors affecting the distribution of juveniles in nursery areas and of adult prawns, the distribution of spawning stock, transport of larvae, growth of juveniles, catchability and population dynamics for fishery assessment (see List of References). For the most part research on W.A. prawn fisheries has been undertaken by the State Department which has the constitutional authority for managing fisheries in State territorial waters. However, research on the banana prawn fisheries to the north of the State was, until 1974, undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Hynd, unpub). That organisation has in recent years confined its prawn research to the fisheries of the Northern Territory and Queensland.

Information from the Fishing Industry—in addition to the contributions made by the fishing industry to the data requirements listed above, there is a continuing verbal and written dialogue between the fishing industry and the W.A. Department of Fisheries and Wildlife and its Research and Inspection Branches.

IV BIOLOGY AND LIFE HISTORY

The biology and life history of species of importance to Western Australian prawn fisheries were described in a comprehensive review by Walker (1975). Full accounts have been given of the biology and life history of western king prawns in Cockburn Sound (Penn, 1975, 1976) of western king and brown tiger prawns in Shark Bay (Penn and Stalker, 1979) and of brown tiger prawns in Exmouth Gulf (White, 1975a and b). It is important to note that the western king prawn is generally a temperate water species extending north of Shark Bay and Exmouth Gulf. The brown tiger prawn is a tropical species which is at the southern end of its range in Shark Bay, while the southern limit of the distribution of banana prawns is at Exmouth Gulf.

The attached List of References contains titles of all publications concerning prawns in Western Australia, whether referred to in the text or not. Not listed are the unpublished works of the late J. S. Hynd (CSIRO) on banana prawns in W.A. and papers published by CSIRO on banana prawns in other parts of Australia.

V ADMINISTRATION OF THE FISHERY AND THE RESEARCH PROGRAMMES

The prawn fisheries of Shark Bay and Exmouth Gulf are administered by the Western Australian Department of Fisheries and Wildlife under the Western Australian Fisheries Act. The purpose of the Act is "for the regulation of the fishing industry and fish farming and for the conservation and management of fisheries and aquatic animal and plant life and for purposes connected therewith" and the regulating authority resides with the Minister for Fisheries and Wildlife.

The fishery was first developed in the early 1960's after a period of test fishing by a Departmental research vessel. Interest in the potential of Shark Bay as a prawn fishery was shown by at least one prawn fisherman from the east coast of Australia who was reported as having ideas of organising for up to 50 east coast prawn trawlers to travel to Shark Bay to take advantage of the resource potential. However, interest was also developing within Western Australia especially by the owners of a whaling company at Carnarvon situated at the northern end of Shark Bay. This station closed after the 1962 season because of a lack of whales due to extreme overfishing. The company was thus conscious of the overfishing problem in a general sense and urged the Government of Western Australia to take appropriate action to ensure that a cautious approach was adopted to the development of a prawn fishing fleet. This overture to Government was generated at least to some extent by the threat of large numbers of prawn trawlers being brought to Shark Bay.

The response of Government was to take a decision to limit the number of prawn trawlers even though the fishery was very much in its infancy. License limitation as an aid to management was a relatively new concept, especially for a fishery which had not yet been developed and it is interesting to speculate whether it would have been introduced if one of the parties interested in the prawn resource had not been forced to close down its whaling station because of overfishing and if there had been no report of a substantial fleet moving to Shark Bay. A decision to limit entry to the Shark Bay fishery in 1963 was followed by a decision to limit entry also to the Exmouth Gulf fishery north of Shark Bay in 1965.

Nearly twenty years of experience has now been gained in relation to the administration of prawn limited entry fisheries and its relative success has resulted in other fisheries being considered for limited entry. In retrospect, the developing Shark Bay prawn fishery was one which had many of the attributes required for the successful administration of a limited entry philosophy. Even so, its introduction has not guaranteed success in ensuring the maintenance of the prawn stocks at a consistently high level.

Some of the major attributes were:—

(a) The whole of the life cycle, or at least that segment likely to be exploited, of the prawn species involved in the fishery was encompassed within the limited entry boundary.

(b) The fleet had not developed to the extent that there was already more catching capacity than required to successfully exploit the stocks.

(c) The stock had the potential to provide a resource which could be exploited by the authorized fleet for at least the major portion of the year.

(d) With the exception of a seasonal fishery on snapper, which was then being exploited only by limited entry rock lobster fishermen from farther south, there were no fisheries in the area to which the prawn trawlers might be attracted as a sideline activity and thus be a cause for concern by other fishermen.

Experience has shown that the administration of a limited entry fishery is much more difficult if any one of these four attributes do not apply. Experience from the Shark Bay prawn fishery and the rock lobster fishery has also demonstrated that there is merit in identifying maintenance of the stocks as the prime objective of a limited entry policy, whilst being aware that such a policy will have considerable economic ramifications, rather than set as a prime objective that of economic management. Controlling the combination of size at first capture and fishing effort and understanding the effect of fishing on the resource is difficult enough for a fisheries administrator, but more difficult still is the problem of coping with economic factors such as changing costs and market prices.

One of the advantages of a limited entry fishery is that there is a precise record of the operators who comprise the industry and they develop a responsible concern for the fishery of which they are a part. There is thus considerable scope for meaningful discussions between government and industry aimed at maintaining the fishery and gaining maximum benefit from the resource. Provided the research programmes can be shown to be competently carried out and directed towards the essential element of fisheries management, industry is receptive to changes in management strategy even though some changes will be of an experimental nature rather than as a result of a clearly demonstrated benefit.

The cost to the State management authority of administration, inspection and research specifically relating to the commercial prawn fisheries amounted to *ca* A$183 000 in 1980–81, which represented 1·5% of the gross local value (A$12·2 m) of the catch. Of this 8% was for administration, 29% for inspection and 63% for research, including data processing. It is of interest to compare these figures with the quite different figures for the W.A. rock lobster fishery in 1979–80 (Hancock,

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1981) i.e. A$1·35 m, representing 2·5% of the value of the catch and comprising 18% for administration, 61% for inspection and 21% research. This reflects the lower total and percentage cost of administering and controlling the prawn fishery. Despite the higher percentage cost of prawn research it is less than half the absolute cost of rock lobster research. Total revenue to the Government from the prawn fishery amounted to $113 000. This includes a small amount from personal fishing licenses of $14 and boat license fees of $30. The limited entry license fees of $1 800 per vessel in Shark Bay and Exmouth Gulf and $200 in Nickol Bay are paid into a trust fund for fisheries research and development.

VI OBJECTIVES OF MANAGEMENT

Various definitions of the management objectives for the Western Australian prawn fisheries have been given and referred to in the literature e.g. Bowen (1975) listed the main considerations as economic viability of the fishing unit, economic viability of the processing establishment and the effect of exploitation on the prawn resources of the Bay. Hancock (1974) suggested that "In terms of practical management the desired result will probably be a compromise between the attainment of the greatest benefit to the community in terms of maximising the yield from the fishery and maintaining an adequate return on capital by the individual boats; i.e. somewhere between the maximum economic yield and the maximum sustainable".

There may be merit in giving a more precise definition of the objectives of management for the limited entry prawn fisheries in the light of the added experience of management. This definition will need to take cognisance of the relatively recent view of the possibility of recruitment overfishing (Penn, in press) as well as economic considerations.

In simple terms then, the prime objective must be "The maintenance of the resource at a level approaching the maximum sustainable yield, while giving proper attention to the economic viability of the fishing units with a view to maintaining a profitable industry".

In achieving this objective, a continuing flow of information is required on:—

(i) the dynamics of the fishery, epsecially in relation to the possibility of growth and recruitment overfishing;

(ii) the economics of the fishing units, including the value of the license goodwill; and

(iii) the economics of the processing and support facilities.

VII MANAGEMENT MEASURES

Limited entry—limitation of the number of boat licenses was introduced into W.A. as a management philosophy in 1963, when the prawn fishery of Shark Bay and the rock lobster fishery of Western Australia were made the first two limited entry fisheries in Australia, at a time when there were few examples of license limitation in the world. License limitation was extended to the prawn fisheries of Exmouth Gulf in 1965, and to Nickol Bay in 1971. This form of management has been used for only two other fisheries in Western Australia, the Australian salmon (*Arripis trutta esper*) and abalone fisheries.

Closed season—the length of the prawn season is not regulated, though summer (Nov-Feb) fishing is controlled by strong winds and low abundance of prawns.

Closed areas—there is a permanently closed nursery area in Shark Bay, to which in recent years has been added the temporary closure of an extended area to allow juvenile prawns to achieve an acceptable market size before the closure is lifted in mid-April. In Exmouth Gulf, there is a permanently closed nursery area and a temporary nursery area which is closed from 30 November to 28 February. This temporary nursery zone often remains closed to April by industry agreement.

Vessel size—there are no regulations governing vessel size which is largely limited by economics. However, since 1977 there has been a tendency towards larger boats to take advantage of the Government boat-building subsidy for vessels over 21 m.

Number and size of nets—in 1976, as a curb on future increases in vessel size, a limit of 14·63 metres (48 ft or 8 fathoms) was placed on the total headline length of trawls and the number of trawls limited to two per vessel in Shark Bay and Exmouth Gulf. There are no mesh size restrictions for prawn nets, but mesh size is controlled for scallop trawling in Shark Bay.

VIII STANDARDISED AND EFFECTIVE FISHING EFFORT

To be of any value in stock production models the unit of fishing effort needs to be apportioned to the individual species and to be standardised so that catch per unit of effort figures can be considered to be more representative of abundance as a time sequence.

Hancock (1974) summarised procedures for the standardisation of catch and fishing effort data leading to estimates of fishing effort and Hall and Penn (1979) followed by Penn and Hall (in prep) have modified these and presented them in greater detail, including the use of the data in stock production models.

In summary these procedures are as follows:—

(i) Tabulate monthly catch by each boat, separately for each species.

(ii) Tabulate monthly catch for each region (trawling area) of the fishery.

(iii) Calculate relative fishing powers for each boat in the fishery using the method of Gulland (1956).

(iv) For those boats which fished in any two successive years with the same skipper and engine, relate the relative fishing power in pairs of years to provide conversion factors to standardise fishing effort against 1973 effort levels.

(v) After standardising the fishing effort of each boat, obtain estimates of average catch rate for each species for each region of the fishery, using multiple regression to estimate catch rates in those regions which were not fished in some months.

(vi) Convert catch rates and monthly catches to numbers using the average weight of the species for each region and month.

(vii) Calculate the average catch rate (numbers/hour) for the whole area for each month using regional catch rates weighted by the area within each region. (As indicated by Hall and Penn (1979), further work is planned to apportion the effort directed towards each species and

subsequently weighting regional catch rates by area occupied by suitable habitat (sediment type within each region).)

(viii) Estimate the average monthly catch rate for the period from January to October.

(ix) Divide this estimate into the total annual catch to give an estimate of annual effective effort for the species.

Penn and Hall (in prep) have defined this estimate of effective effort as "The ratio of catch (in numbers) of the species to the average catch per standardised unit of effort, where the average catch rate is calculated over all areas for each month and then averaged over the months from January to October. This effort unit is corrected for the effects of concentration (spatial and temporal) of fishing effort on the stock".

There remains to be borne in mind the effects of various unquantifiable influences. While vessel size, seasonal catch rates and in some measure, area distribution of fishing effort and any increases in net size up to the permitted maximum, have been given due weight in calculations, changing levels of operator efficiency and technology may be reflected in additional unrecorded changes in effective effort. It might be expected that the latter would now be of minor importance in the highly developed fisheries which have been operating for nearly twenty years in Shark Bay and Exmouth Gulf, but a recent tendency which is likely to increase is improved location of stock aggregations using sophisticated navigation aids.

IX ASSESSMENT OF THE FISHERY

A. Past History

Hancock (1974) has described the introduction of the limited entry system of management into the prawn fisheries of Western Australia. The approach adopted in 1963 for Shark Bay and in 1965 for Exmouth Gulf was similar to that subsequently recommended by Gulland (1972) i.e. to issue licenses in some arbitrary number not expected to exceed the long term optimum and by a process of iteration to gradually improve estimates of that optimum on the basis of data gathered, accordingly modifying (in this case increasing) the number of licenses, in a stepwise fashion.

In Western Australia in recent years there has been a triennial review followed by any appropriate change in the number of licenses. Hancock (1974) summarised the procedures for assessing the desirable number of licenses for the 1975–1977 triennium, while Penn and Hall (in prep) have presented full details of a similar assessment to set the number of licenses for 1978–1980. This included reference to economic data supplied by the Commonwealth Department of Primary Industry.

The recommendation was made that the number of Shark Bay licenses for the 1975–1977 triennium should be 35, the additional 3 licenses being issued as Provisional Licenses with no obligation for renewal at the end of three years. This was to allow for a trial assessment of the practical and economic consequences of the increase before reaching a decision about the permanent status of the new licenses and recognised that a step-by-step approach need not always be forward, but should be flexible enough for a step backward should any unpredictable changes occur. In the event, from the assessment of data up to and including 1977, it was concluded that the indications of an expanding fishery were less obvious than from previous reviews and the option of further additional licenses was not considered. The alternative of withdrawing the 3 provisional licenses was rejected in favour of making them permanent. The current situation will be discussed below.

In Exmouth Gulf, a suggestion to increase the number of licenses from 22 by 3 provisional licenses for 1975–1977 was not adopted because of the past history of variable recruitment (Figure 2) and industry's consequent concern about economic security. However one provisional license was approved for the 1979–1981 triennium, bringing the total to 23.

B. Assessment based on raw data

Figure 2 gives annual catch and total nominal (uncorrected) fishing effort data for Shark Bay and Exmouth Gulf, as a time series. Figure 3 uses the same data to relate annual catch and nominal fishing effort and provides a further eight years of data since Hancock (1975).

Several general conclusions can be drawn from these data:—

Shark Bay

(i) While Figure 3 gives a suggestion that total catch has continued to increase with increasing nominal fishing effort, Figure 2 shows that catches have levelled off in recent years.

(ii) Western king prawn catches appear to be increasing with increasing effort (Figure 3) but there has been little change in catch level over the past nine years.

(iii) Catches of brown tiger prawns in Shark Bay, where it is the minor species, are quite variable and appear not to have increased for the past ten years, either annually (Figure 2) or as a function of increasing nominal effort (Figure 3). During this period there was an unusually low catch of brown tiger prawns in 1972, which was compensated for by good catches of western king prawns (Figure 2). Average catches followed until 1978 following which the catch of brown tiger prawns declined in 1980 to the lowest recorded since the commencement of this fishery. The 1981 catch of this species is also expected to be of a similar order.

(iv) The low total catch in 1977 was obtained at an unusually low catch per unit of effort and was a feature of catches of both species.

(v) Nominal fishing effort in Shark Bay has changed a relatively small amount since 35 vessels were permitted to fish in 1975. However it will be seen from section C below that effective effort has shown a marked increase especially in recent years.

Exmouth Gulf

(i) From Figures 2 and 3 it can be seen that annual catches are much more variable than in Shark Bay. This variability comes mainly from the major species, brown tiger prawns.

(ii) Total catches from Exmouth Gulf appear to have increased with increasing fishing effort (Figure 3), while Figure 2 is more suggestive of a general decline since 1975. The catches of brown tiger prawns appear to have been mainly responsible for this decline and when

related to nominal effort the suggestion is that there has been no recent increase in catch with increasing effort.

C. Assessment based on effective fishing effort

Figure 4 shows the estimates of effective effort for the two species calculated using Penn and Hall's (in prep) method described above, related to annual catches in numbers of each species. This analysis has so far been undertaken only for Shark Bay.

A range of functions was fitted to the data, based on the assumption of equilibrium for a single year-class stock. These were the generalised production model (GENPROD) (Pella and Tomlinson, 1969), the asymptotic yield model (i.e. Genprod with $m = 0$), Fox's (1970) model (Genprod with $m = 1$) and Schaefer's (1957) well known stock production model (Genprod with $m = 2$). Residual sums of squares were calculated (Table 5), and approximate 95% confidence limits obtained using the method of Bard (1974 p. 204). Further details of methods are given in Penn and Hall (in prep).

The generalised production model appeared to give an acceptable representation for both species, and in the case of the western king prawn was virtually coincident with the Fox model (Table 5). For brown tiger prawns Genprod and asymptotic yield models gave similar results over the range of the data.

The fits of the generalised production model to the data, together with approximate 95% confidence limits have been given in Figure 4, together with fitted Schaefer curves. These will allow comparison with the results of Rothschild and Parrack (in press) for the Gulf of Mexico fishery.

Table 5 indicates a maximum sustainable yield (MSY) for western king prawns of around 50 million individuals for an optimum fishing effort of 90 000 effective hours trawling from the Genprod and Fox models, and 80 000 from Schaefer's. This compares with the current level of effective fishing effort of *ca.* 100 000 hours.

The MSY indicated for brown tiger prawns is around 21–22 million individuals (Table 5) for an optimum fishing effort of 62 000 hours (Schaefer) or 54 000 hours (Fox). (The Genprod fit had an m value close to that of the asymptotic yield function, and therefore produced a virtually infinite optimum effort figure). Effective effort exceeded 80 000 trawling hours in 1979 before falling to around 64 000 in 1980 at the time of the lowest catch of brown tiger prawns (Figure 2). It has been noted that low catches were experienced in 1972, but this was at a time of only modest fishing effort for both species. The 1980 result must therefore be viewed against the much higher level of fishing effort which preceded it, and the fact that 1981 is also expected to provide less than average brown tiger prawn catches.

Penn (in press) made the very important observation that the level of effort expended on the reduced available stock during 1980 could not have occurred without the availablility of the second species on the same grounds which made the combined catchrate economically viable. In other words, a species may continue to be fished beyond the point where falling catch rates would otherwise have discouraged continued exploitation. High value species, such as the brown tiger prawn, would be specially vulnerable to this situation. More generally, Penn (pers. comm.) has noted that the fishing effort directed towards areas suitable for brown tiger prawns (the minor species) is sometimes relatively greater than for western king prawns. This may occur when western king prawn catch rates are poor, as in 1966 and 1967 (Figure 2), or it may also be that the fishing effort directed towards brown tiger prawn habitat yields also western king prawns to give an economically viable combined catch rate.

D. Economic assessment

The definitions given under the section "Objectives of management" indicate clearly the need for an understanding of fishery economics. The prawning industry expects, and prefers, to make its own economic decisions. However, proper management of the resource must relate such economic decisions to the wellbeing of the stocks, which cannot be achieved from assessments based only on quantities caught and fishing effort expended. Economic data and opinion provided by the Commonwealth Department of Primary Industry (Anon, 1970, 1975; Meany, 1979 and Owen, 1981) are therefore of the utmost importance to the triennial assessments of the fishery.

DPI's reports have given figures for percentage return on capital as "market value, without concession", which are quoted as follows:—

	Shark Bay	Exmouth Gulf
1966–67	29·2	37·2
1967–68	25·8	32·7
1971–72	21·6	loss
1972–73	25·4	30·0
1973–74	24·4	15·4
1974–75	11·8	10·0
1975–76	50·0	43·2
1976–77	39·0	19·7

For Shark Bay, the latter three years surveyed, which averaged 33·5 per cent on capital, ranged from 11·8 in 1974–75 to 50·0 per cent in 1975–76. In 1974–75 the price of $1.83 per kg did not compensate for rising fuel and vessel costs, but by 1976–77 the price had doubled to $3.69 per kg.

The comparable percentage return on capital, when the resale value of the concession was included, for 1976–77 was 18·5 (cf 39·0 for market value without concession). A significant comment (Anon, 1975) for the 1971–72 to 1973–74 period that was within each financial year, rates of return were widely spread, with nearly 20 per cent of trawlers achieving in excess of 50 per cent return on capital each year, while a smaller proportion recorded losses on their operations.

Owen (1981) commented that the return on capital represents a higher rate than that available on "gilt-edged" investments (Government bonds, etc.). However, noting the risk factor, e.g. a series of low production years, low prices or damage or loss of a vessel, he believed the return must be considered "reasonable".

However in the years since Owen's (1981) assessment i.e. 1978–80, the additional operating costs related to fuel and related products and declining prices (1980–81) for prawns resulting from exchange rate variations and competition in Japan between Chinese and Australian products, together have made the fisheries generally less profitable. These changes coupled with the over-capitalisation of concessions particularly through the building of larger vessels allowed by the highly profitable years of 1978–79, appear to have resulted in an overall decline in profitability which may be difficult to reverse.

The comparable figures for Exmouth Gulf (market value, without concession) for 1974–75 to 1976–77 were 10·0, 43·2 and 19·7 per cent respectively, which are lower than for Shark Bay, but which to Owen (1981) "demonstrate that the fleet has certainly achieved more than satisfactory returns over the survey period" It should be noted (Table 3) that catches during the three survey years were at or above the 10 year average, and that annual catches from Exmouth Gulf are generally more variable than from Shark Bay. It can be seen from the table above that in 1971–72, when poor catches were experienced, there was a small average loss.

E. Current assessment

Shark Bay

Several trends in the Shark Bay assessment which need to be viewed with some concern are (1) the recent increase in effective fishing effort (Figure 4), by the same number of boats, resulting from increased net and vessel size, (2) the decline in brown tiger prawn catches, particularly since this has followed a decade of catches which have not increased with increasing fishing effort, (3) the current effective effort levels which, at least for western king prawns are in excess of the optimum required for MSY and (4) the apparently less healthy economic situation of recent years which willl reflect the consequences of (1) and (2). Short lived downturns in catches have occurred in previous years e.g. for western king prawns in 1965–68 and brown tiger prawns in 1967–69 and 1970–72, but these could usually be explained by increased effort for the alternative species, and in any case took place at lower effective effort levels.

In view of the above trends, which will be monitored and evaluated carefully, there is unlikely to be any justification for increasing the number of boat licenses in the foreseeable future.

Exmouth Gulf

In Exmouth Gulf, where the fishery appears to be in a similar state of exploitation to Shark Bay, the situation is compounded by the greater variability of annual catches. Additional data analysis is required, but a preliminary view would be to discourage any further expansion of fishing effort.

X EFFECTIVENESS OF MANAGEMENT MEASURES

1. The fishery has remained viable and annual catches from both Shark Bay and Exmouth Gulf have remained relatively stable in recent years despite increased effective fishing effort.
2. The number of licenses for Shark Bay was increased to 35 in 1975. During the following few years the level of effective effort remained less than the optimum effort required for maximum sustainable yield predicted by GENPROD for both western king and brown tiger prawns. However despite an unchanged number of boats the effective effort rose during 1979 and in the case of western king prawns, in 1980 exceeded the estimated optimum effort (Figure 4). Escalation of effective fishing effort within a limited entry fishery is also a feature of the Western Australian rock lobster fishery (Hancock, 1981). In the Shark Bay prawn fishery it will have resulted for the most part from the introduction of larger vessels with to some extent an increase in size of net (see below). However, at least up until 1977 the fisheries of both Shark Bay and Exmouth Gulf were considered to be economically viable (Owen, 1981).
3. Temporarily and permanently closed nursery areas have been relatively successful in protecting the physical environment of nursery areas from trawling damage, but their value in limiting catches to a size range of commercial usefulness has been very much dictated by market demand i.e. in years of demand for small prawns, operators concentrate on nursery borders whereas in other years they would have fished larger prawns more distant from nursery areas. Yield per recruit consequences of the different fishing strategies have not been computed.
4. *Closed season*—The need for a closed season for W.A. prawn fisheries has been reviewed from time to time but to date no obvious advantage has emerged. Hancock (1972) concluded "there is no evidence to suggest that, under the conditions which have existed in the Shark Bay fishery in recent years, a close season from 1 September to the end of February (requested by fishermen) would have contributed significantly either to the survival of spawning females and subsequent success of recruitment, or to improved catches following lowered fishing effort on young prawns entering the fishery from nursery grounds." This assessment still holds good, since recruitment to the trawl grounds does not usually occur before March (Penn, pers. comm.) and the major reduction in stock, and subsequently in number of spawners, occurs before September (see also paragraph XI, A, 9 below).
5. *Number and size of nets*—The maximum headline length and the restriction to two nets were introduced in 1976 as a measure to place an upper limit on the unit of effort, (a similar restriction limiting pot size has been employed in the W.A. rock lobster fishery). The choice of headline length of 14·63 metres was however a compromise between the intention to control fishing effort from this cause and to accommodate existing gear. In the event there has been a tendency when replacing gear, despite a previous apparent preference for a smaller size (12·8 m), to upgrade nets towards the maximum permitted.
6. *Vessel size and fishing power*—The decision to restrict the number and size of nets was intended to discourage the building of larger replacement vessels qualifying for the shipbuilding subsidy, which had previously (1971–73) proven uneconomic in both Shark Bay and Exmouth Gulf. However, the shipbuilding subsidy has still encouraged the building of larger vessels which have utilised the maximum net size permitted and caused significant increases in effective fishing efforts especially in 1979–80 (Figure 4). The control on nets has therefore been only partially successful in containing fishing effort, but noting that there would undoubtedly otherwise have been a tendency towards more nets per vessel as in the Gulf of Carpentaria.

XI RESEARCH AND MANAGEMENT CONSIDERATIONS

A. Research

1. *Stock recruitment relationships*—Boerema (MS) believed that there is little danger of a fishery for penaeid prawns developing to such a level that insufficient spawners remain. Owen (1981) concluded that "Biologists generally agree that the penaeid species, because of their high fecundity and short life span, withstand considerable fishing pressure without either

lower recruitment or smaller size of prawns taken resulting in a reduction in total catch". These widely held views, which put the emphasis on economic, rather than biological, management, are now being challenged (Penn, in press; Rothschild and Parrack, in press). Only future events will show whether the tiger prawn stocks in Shark Bay are showing recruitment over-fishing as a consequence of excessive fishing effort.

2. *Growth overfishing*—also becomes a possibility when excessive effort is concentrated into times (early season) and areas (close to nursery grounds) in which young, small prawns predominate.
3. *Variability of data*—environmental variables e.g. temperature, salinity, rainfall, cause variability in recruitment which can hinder interpretation of trends in catch and effort data as well as exaggerating any consequences of recruitment overfishing. Variability of catch data also seems to be a feature of higher effort levels.
4. *Quantification of effective fishing effort*—while seasonal and spatial catchability influences, vessel size/fishing power and net size trends can be allowed for in the estimate of effective effort, only qualitative recognition can be given to improved operator and technological efficiency. This could result in a failure to recognise insidious increases in effective fishing effort in stock production groups.
5. *Nominal and effective effort*—it can be seen above that assessments based on nominal fishing effort can be quite misleading and mask changes in effective effort. Hancock (1981) similarly found for rock lobsters that yield analyses based on nominal effort gave much more optimistic results than for effective effort.
6. *Stock production models*—traditionally accepted models have been fitted and except where data are highly variable e.g. brown tiger prawns in Exmouth Gulf, give reasonably consistent results. Their application to short lived species should give meaningful equilibrium representations. However, they must be considered to be *descriptive* rather than *predictive*.
7. *Separation of fishing effort in mixed species fisheries*—Hall and Penn (1979) have addressed this problem for Shark Bay, but use of the separated effort data requires an intimate knowledge of species requirements for and distribution of habitat within trawling grounds, which is not yet available for Exmouth Gulf. Knowledge of "intention to fish" (see above) would then assume importance.
8. *Nursery area closures*—the experience of Shark Bay is that these are of value in protecting the physical environment but their practical effectiveness in adjusting commercial size has proved to be a function of current marketability. Yield per recruit predictions will remain essentially subjective pending useful natural mortality estimates and will require an intimate knowledge of migration paths and seasonal fishing patterns.
9. *Closed season issues*—while the view has been that a summer closed season would serve little useful conservation purpose in Shark Bay, this will need to be reviewed carefully in the light of suggestions that penaeid recruitment may become affected by intense exploitation.
10. *Collection of research data*—the value of detailed information through a logbook system has been highlighted above, one of its greatest advantages being the timely availability of fully analysed data for management purposes. However it is costly in labour and expense to maintain effectiveness. A recent attempt to reduce some of the detail required e.g. to use engine hours and landed weights rather than daily log records has proved inopportune (Penn, pers. comm.) because it unexpectedly coincided with a time of lowered brown tiger prawn catches which required investigation based on detailed data. On the other hand the annual cost of data collection of less than $70 000 from prawn fisheries valued at first sale at approaching $20 million seems well justified.
11. *Additional licenses*—the quite arbitrary system of 3 year reviews and augmenting the number of licenses by three, has been quite successful in providing fishing effort increments adequate for statistical interpretation, despite annual variability of stocks. However the dangers in this practice of overshooting optimum effort where effort per license is not fully controlled are clearly to be seen and not only is there a requirement for a statistically significant increment in fishing effort, but also for an adequate period of time for assessment (see also (2) below).

B. Management

1. The problem of *escalating effective effort* within a fishery in which the number of boats is limited appears to be common (see also Morgan, 1980; Hancock, 1981; for W.A. rock lobsters). Clark (1980) reasons "each licensed fisherman will be motivated to undertake any action that will increase his share of the catch." This can occur contrary to economic wisdom and in Western Australian prawn fisheries has manifested itself in increasing net sizes and larger, more powerful, boats and to some extent, particularly during the early 1970s, prolonging the fishing season.
2. Clark (1980) has commented that limited entry systems are prone to *overshooting MSY* and experience from Shark Bay has shown that this will still happen, despite carefully modulated increases in the number of licenses, unless the fishing unit is fully controlled. The importance of caution in increasing licenses at a time of high fishing effort is underlined by the Shark Bay experience, where effective effort remained steady for four years when 3 licenses were added in 1975 to give 35, but in the following two years (1979 and 1980) vessel replacements caused effective effort to increase greatly (Figure 4).
3. Reduction of fishing effort within a limited entry fishery is not easy (see also for rock lobsters—Hancock, 1981) particularly where concessions have acquired a high transfer value. While the issue of provisional licenses is a theoretical means of allowing a retreat from over-exploitation in a limited entry fishery, the withdrawal of such licenses has yet to be put into practice.

   In practical terms, once a provisional license is issued it becomes politically difficult to withdraw that license, except where the vessel involved has been taken from an economically successful fishery, e.g. for rock lobster, to which it can be returned with no additional capital expenditure. In practice high capital cost is likely to be involved in providing specialist boat and gear. Such decisions therefore put a greater responsibility on data acquisition and

analysis and while acknowledging the need for full exploitation, the conclusion on issue of additional licenses must be to defer decision making while there is any doubt about the outcome. This view is in accord with one of the principles drawn up at Airlie in 1975 (*cit.* Gulland 1977) i.e. "Management decisions should include a safety factor to allow for the facts that knowledge is limited and institutions are imperfect".

The alternatives to reducing the number of licenses involve controls on individual efficiency, which must only be considered against the background of economic viability of the individual units, or reducing individual catching units to an economic size.

4. The high market value of transferable licenses has added substantially to the capitalisation of the industry. The result, particularly for new entrants to the fishery with large bank loans to service, will be for competition to achieve maximum catches with associated pressure on the stocks.
5. The traditional view for uncontrolled fisheries is that at high levels of fishing effort, biological over-exploitation is likely to be averted by boats leaving the fishery because of its economic unattractiveness, to fish alternative stocks. However at levels which appear to be at least approaching over-exploitation, especially for the minor species in Shark Bay, the industry was on the average, at least until the 1976–77 economic survey, apparently economically viable. More recent experience may differ from this view and certainly the largest vessels have been economically less successful. It is also true that some years ago individual boats made losses within the limited entry fishery at a time when the average return on capital was good.
6. Of concern is the knowledge that fishing may be maintained on low stock levels of one species by virtue of supporting stocks of another prawn species and therefore contribute to overfishing in a situation which otherwise would be self regulating. Presumably any by-catch would have the same effect.
7. Similarly a requirement for licensed vessels to continue to fish in the concessional area could be instrumental in maintaining fishing pressure on otherwise unattractive stocks. Vessels licensed to fish Shark Bay and Exmouth Gulf were obliged to fish in the concessional area from 1 May to 31 July but this regulation was rescinded in 1976.
8. A factor of importance to understanding the implications of vessel size in W.A. prawn fisheries particularly, is that the duration of economic fishing season is inversely related to the size of the vessel (Penn and Hall, in prep.). For example in Shark Bay outside of the peak catching season, catch rates fall below the economic break-even point of vessel operation. The larger vessels will therefore need to seek some alternative fishery to maintain economic viability. In earlier years the Gulf of Carpentaria provided this safety valve, but fishing for prawns there is now confined to vessels with a Gulf limited entry fishing concession and includes only a few Shark Bay boats. Apart from limited banana prawn stocks which have been located in coastal waters of Admiralty Gulf and farther north, exploratory fishing has so far failed to locate fishable stocks in Western Australian waters. Consequently there are now few alternatives but to lay up boats until the following season.
9. Limitation of entry into selected fisheries, particularly if they are successful, seems to set in train two reactions by the fishing public (a) to demand more limited entry fisheries, often for quite inappropriate situations, and (b) to want licensed fishermen to be barred from alternative open fisheries on the grounds that they are already operating profitably and do not need further income. (a) is often a suggested way of achieving (b). So the scallop fishermen of Shark Bay would like to preclude prawn fishermen from fishing scallops, the snapper fishermen of Shark Bay believe licensed rock lobster fishermen should not be allowed to trap snapper and so on.

   The prime objective of a limited entry policy is the maintenance of the resource. Economic considerations follow, but the economic viability for individual operators is not guaranteed. Fishermen should therefore not be so constrained by an explosion of inappropriate limited entry fisheries to the extent that they lose the opportunity to operate on other resources. When the prawn limited entry fishery was first approved the scallop resource was not being exploited and the snapper resource in the northern part of Shark Bay was being exploited by fishermen who already had a rock lobster limited entry authorisation. Subsequently, the Shark Bay snapper and scallop fishermen have made a decision to expend money to exploit the resources, being aware that they were already being exploited by rock lobster and prawn limited entry boats. To now prevent the prawn and rock lobster boats from moving outside their prime fisheries would have an implicit overtone of Government guaranteeing their profitability from the limited entry fisheries. This would require a degree of economic management by Government to an impracticable degree.
10. It is worth recording that the establishment of a limited entry fishery at a time when fishing was profitable has brought with it a level of co-operation and mutual understanding between managers, research and the members of the limited entry fishery which is not always a feature with other sections of the industry. However this brings with it a special responsibility for data collection, analysis, interpretation and implementation which has its response by the fishing industry in the high level of information provided and the exchange of ideas.
11. The Inspection Branch has had its difficulties in attempting to police lines over water e.g. the boundaries of nursery areas, but these are common to all fisheries. However in a limited entry fishery the potential for removal of a valuable license should act as an additional deterrent.
12. A limited entry system which freely permits transfer of concessions and associated capital value of a license over and above the intrinsic value of the vessel has drawn criticism from some quarters (Meany 1978). It is argued that excess profits (economic rent) from a common property resource should somehow be better enjoyed by the community. Administrators of new limited entry fisheries will need to make a decision on questions of access and benefits. However the view in Western Australia is that fishermen who have enjoyed concessional rights since 1963, have, in the course of 15 years, by now earned them. New entrants are required to buy these rights, albeit at an inflated price depending on the

current profitability of the fishery and therefore gain nothing. However the cost of the licence may make the cost of entry beyond that of potential boat owners, including experienced new fishermen wishing to buy boats of their own.

XII CONCLUSION

The comments of Bowen (1975) remain appropriate to the present discussion i.e.

> "The use of license limitation regulations as a fisheries management tool does provide a method of partially controlling the exploitation rate and capital input. For fisheries such as that on the western rock lobster and Shark Bay prawns it has been of benefit to the State and to the industry. However, its implementation requires close contact between industry, the scientist and the administrator.
>
> "If successfully operated, the measure provides economic security and high profitability, but it also impinges on personal liberties and freedom of choice of fishermen. The manager has to ensure that biological, economic and administrative understanding is at a level which ensures that the fisheries involved are fully developed, monopolies are not created, both Government and industry benefits financially and that if new licenses or authorisations are granted the system of selection is one which is accepted by those interested in obtaining entry into the limited fishery."

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TABLE 1—LANDINGS FROM WESTERN AUSTRALIAN PRAWN FISHERIES (kg x 10^{-3})—1980

	Western King	Brown Tiger	Endeavour	Banana	Total	Maximum No. of Boats*
Shark Bay	1 398·3	252·7	16·9	....	1 667·8	35
Exmouth Gulf	215·9	646·5	191·1	S†	1 053·5	23
Onslow	5·2	72·5	5·1	0·1	82·9	9
Nickol Bay	21·4	35·4	1·2	118·0	176·0	13
Admiralty Gulf	....	....	....	S†	S†	
Total	1 640·8	1 007·1	214·3	118·1	2 980·3	

* Maximum number of boats fishing during any month, but may be present for only part of the year.
† S—small quantities—no records available.

TABLE 2—PRAWN LANDINGS—SHARK BAY, 1962–80

Catches are given in kilograms x 10^{-3}, heads on. Effort is measured in hours trawled. The number of boats is the maximum number fishing during any month.

Year	Catch			Total Catch	Total Nominal Effort	Boats Fishing
	Western King	Brown Tiger	Endeavour			
1962	104·8	46·8	....	151·6	2 420	4
1963	359·4	243·7	....	602·1	9 898	22
1964	505·6	406·6	....	912·2	13 960	28
1965	442·8	396·8	....	839·6	17 861	28
1966	261·2	406·5	....	667·7	19 211	29
1967	227·8	673·3	....	901·1	31 644	30
1968	413·9	499·3	....	913·2	36 379	29
1969	798·3	460·3	....	1 258·6	37 210	27
1970	1 042·7	732·2	....	1 774·9	48 667	32*
1971	937·0	608·5	....	1 545·6	46 483	32*
1972	1 382·8	369·1	....	1 751·9	51 552	31
1973	1 185·6	636·1	....	1 821·7	51 474	33*
1974	1 432·6	667·7	....	2 100·3	51 814	32
1975	1 382·8	770·0	....	2 152·8	55 134	35
1976	1 510·8	771·4	....	2 282·3	61 340	35
1977	1 070·9	550·1	36·3	1 657·4	58 757	34
1978	1 370·6	729·1	12·7	2 112·4	57 244	35
1979	1 439·5	659·5	38·2	2 137·2	62 655	35
1980	1 398·3	252·7	16·9	1 667·8	57 786	35

NOTE: The 1980 data in this table may be subjected to minor revision following more detailed analysis.
* Boats exceed number licensed through standby arrangements.

TABLE 3—PRAWN LANDINGS—EXMOUTH GULF, 1963–1980

Catches are given in kilograms x 10^{-3}, heads on. Effort is measured in hours trawled. The number of boats is the maximum number fishing during any month.

Year	Catch				Catch	Total Nominal Effort	Boats Fishing
	Western King	Brown Tiger	Banana	Endeavour			
1963	1·0	15·1	51·9	S	68·0	1 799*	12
1964	16·6	33·5	60·2	S	110·3	2 063*	6
1965	16·1	135·2	56·9	S	208·2	8 380*	13
1966	72·0	420·5	39·1	S	531·6	11 097*	15
1967	41·3	704·3	22·1	S	767·7	16 651*	17
1968	167·0	212·4	S	S	379·4	17 667	17
1969	76·7	472·9	S	104·9	654·5	26 245	17
1970	208·1	887·7	S	295·4	1 391·2	38 764	20
1971	135·1	233·7	S	150·0	518·8	29 706	20
1972	364·3	672·5	S	210·4	1 247·2	45 039	22
1973	278·1	596·1	0·4	277·2	1 151·8	47 296	22
1974	206·1	515·3	0·6	222·8	944·8	41 478	22
1975	312·1	1 239·4	2·3	450·4	2 004·2	45 066	22
1976	232·9	745·0	17·4	285·9	1 281·2	49 726	22
1977	340·5	639·2	1·2	236·5	1 217·4	51 035	22
1978	376·8	882·7	0·1	423·0	1 682·6	54 388	22
1979	271·5	572·4	S	328·4	1 172·3	51 097	23
1980	215·9	646·5	S	191·1	1 053·5	52 710	23

* Estimates. S—small quantities only.
NOTE: The 1980 data in this table may be subject to minor revision following more detailed analysis.

TABLE 4—PRAWN LANDINGS—NICKOL BAY AND ASSOCIATED AREAS, 1966–80

Catches are measured in kilograms x 10^{-3}, heads on. Effort is measured in hours trawled. The number of boats is the maximum number fishing during any month.

Year	Catch				Total	Nominal Effort	Boats Fishing
	Banana	Brown Tiger	Western King	Endeavour			
1966	10·6	....	....	....	10·6	344	1
1967	476·2	....	....	....	476·2	13 560	22
1968	53·8	....	....	....	53·8	3 219	9
1969	50·3	....	....	....	50·3	710	7
1970	120·9	....	....	....	120·9	2 446	10
1971	185·6	....	....	....	185·6	1 268	10
1972	49·2	....	....	....	49·2	401	5
1973	240·2	....	....	....	240·2	2 209	14
1974	180·6	....	....	....	180·6	1 164	15
1975	176·1	....	....	....	176·1	1 792	11
1976	452·2	....	....	....	452·2	1 655	15
1977	95·4	....	....	....	95·4	2 036	14
1978	92·6	19·6	5·1	....	117·3	4 700	13
1979	20·4	86·2	32·1	6·1	144·8	13 745	16
1980	118·0	35·4	21·4	1·2	176·0	8 827	13

NOTE: 1980 data may need minor revision following more detailed analysis.

TABLE 5—RESULTS OF FITTING FOUR STOCK PRODUCTION MODELS TO CATCH (NUMBERS) AND EFFECTIVE EFFORT DATA FOR (i) WESTERN KING AND (ii) TIGER PRAWNS FROM SHARK BAY 1962–80

	Genprod	Asymptotic Yield	Fox	Schaefer
(i) *Western king*				
m	1·058	0	1	2
Maximum sustainable yield (numbers x 10^{-7})	5·04	7·59	5·04	5·09
Optimum effort (hours trawled x 10^{-4})	8·96	∝	9·13	7·99
Residual sum of squares	6·993E14	7·366E14	6·994E14	7·253E14
(ii) *Brown tiger*				
m	0·0001*	0	1	2
Maximum sustainable yield (x 10^{-7})	2·25	2·26	2·09	2·14
Optimum effort (hours trawled x 10^{-4})	8·490	∝	5·37	6·22
Residual sum of squares	4·651E14	4·651E14	5·955E14	7·024E14

* Lower bound for m allowed in estimation run.

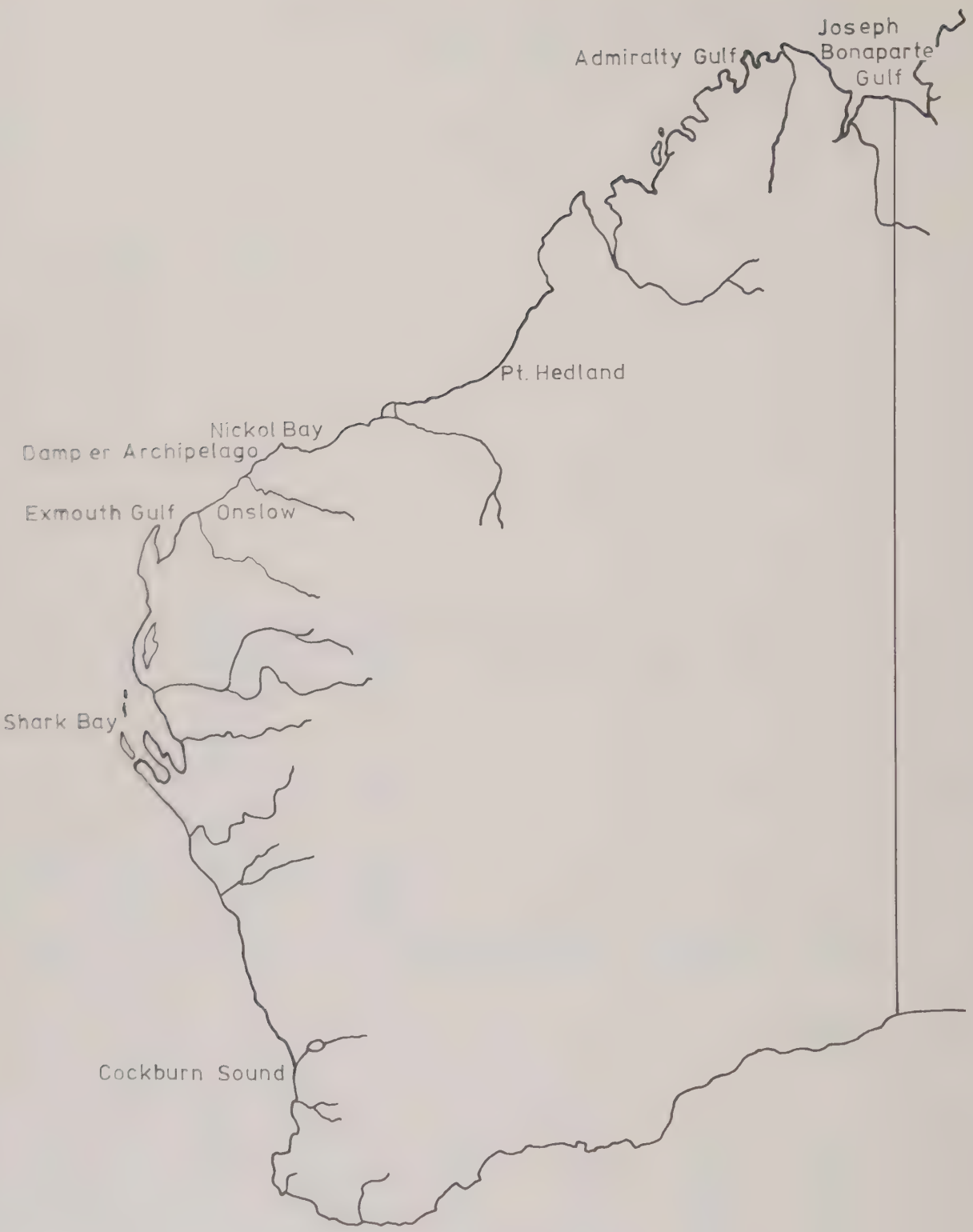

Fig. 1—Sketch Map of Western Australia showing areas mentioned in the text (from Hancock 1974).

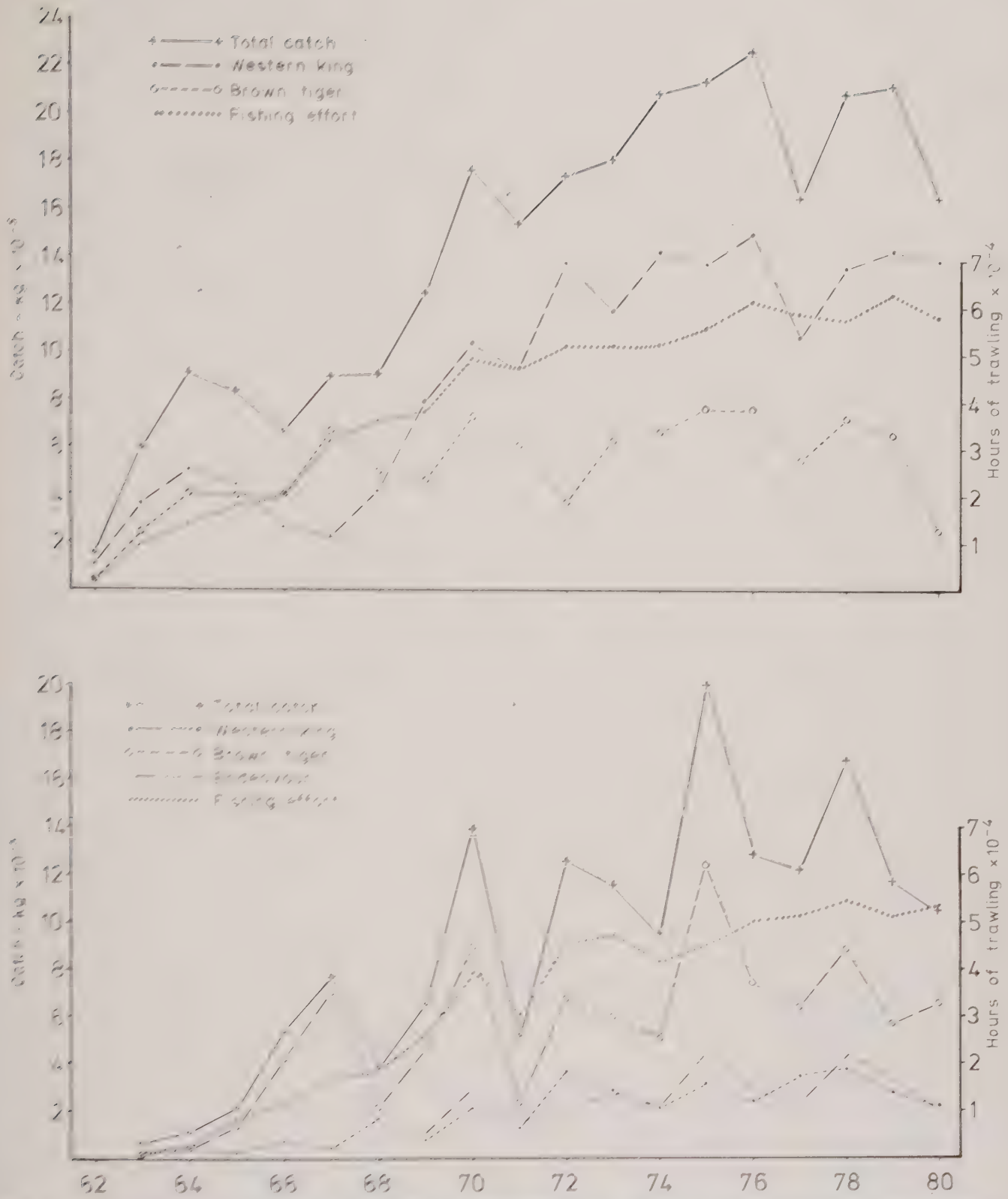

Fig. [illegible] (by weight) of all species combined and individual species, together with annual (uncorrected) fishing effort (in [illegible]) and [illegible] (1963–80)

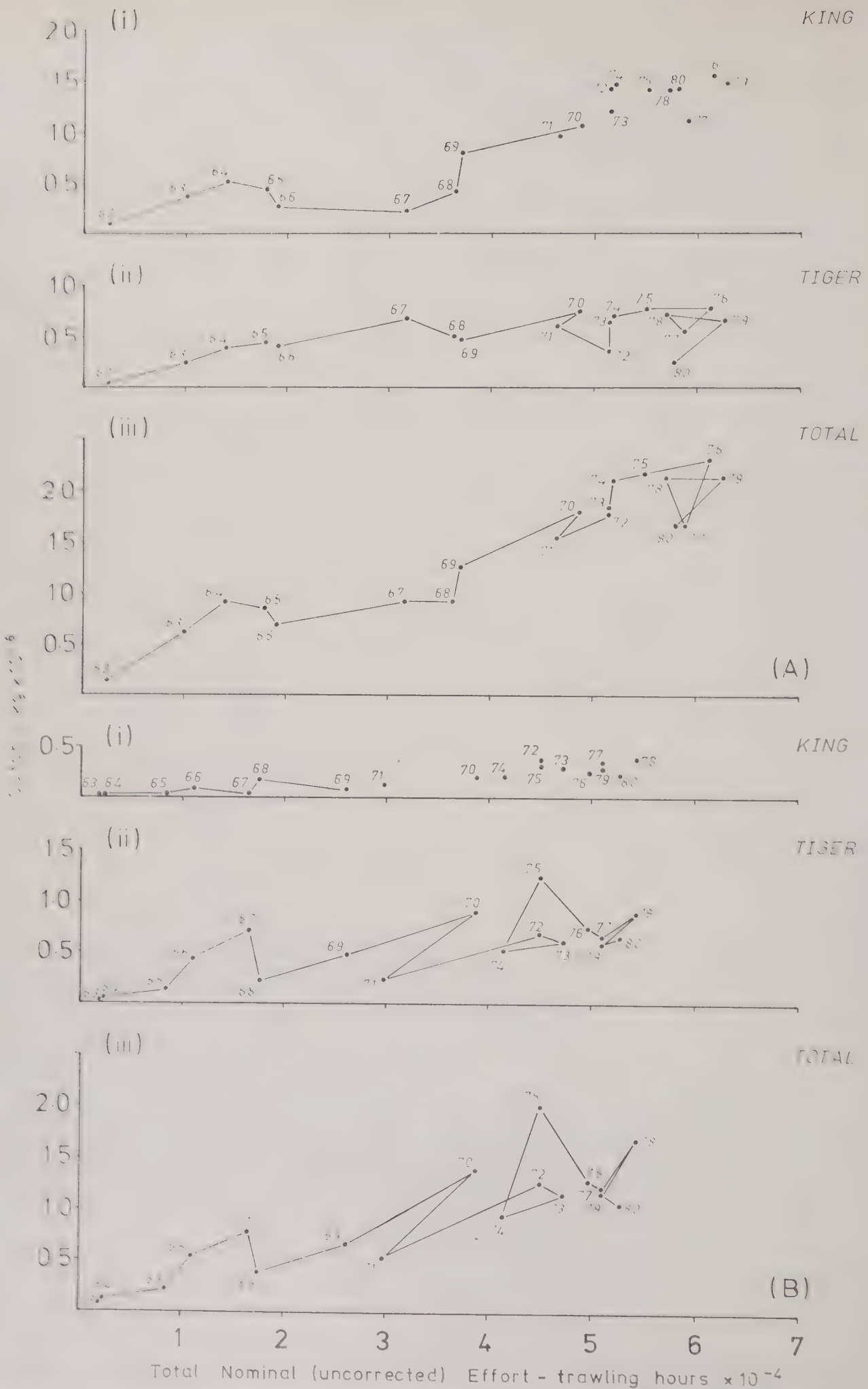

Fig. 3 Annual catches by weight of (i) western king (ii) brown tiger (iii) total prawns for (A) Shark Bay 1962–1980 and (B) Exmouth Gulf 1963–1980, related to annual nominal (uncorrected) fishing effort.

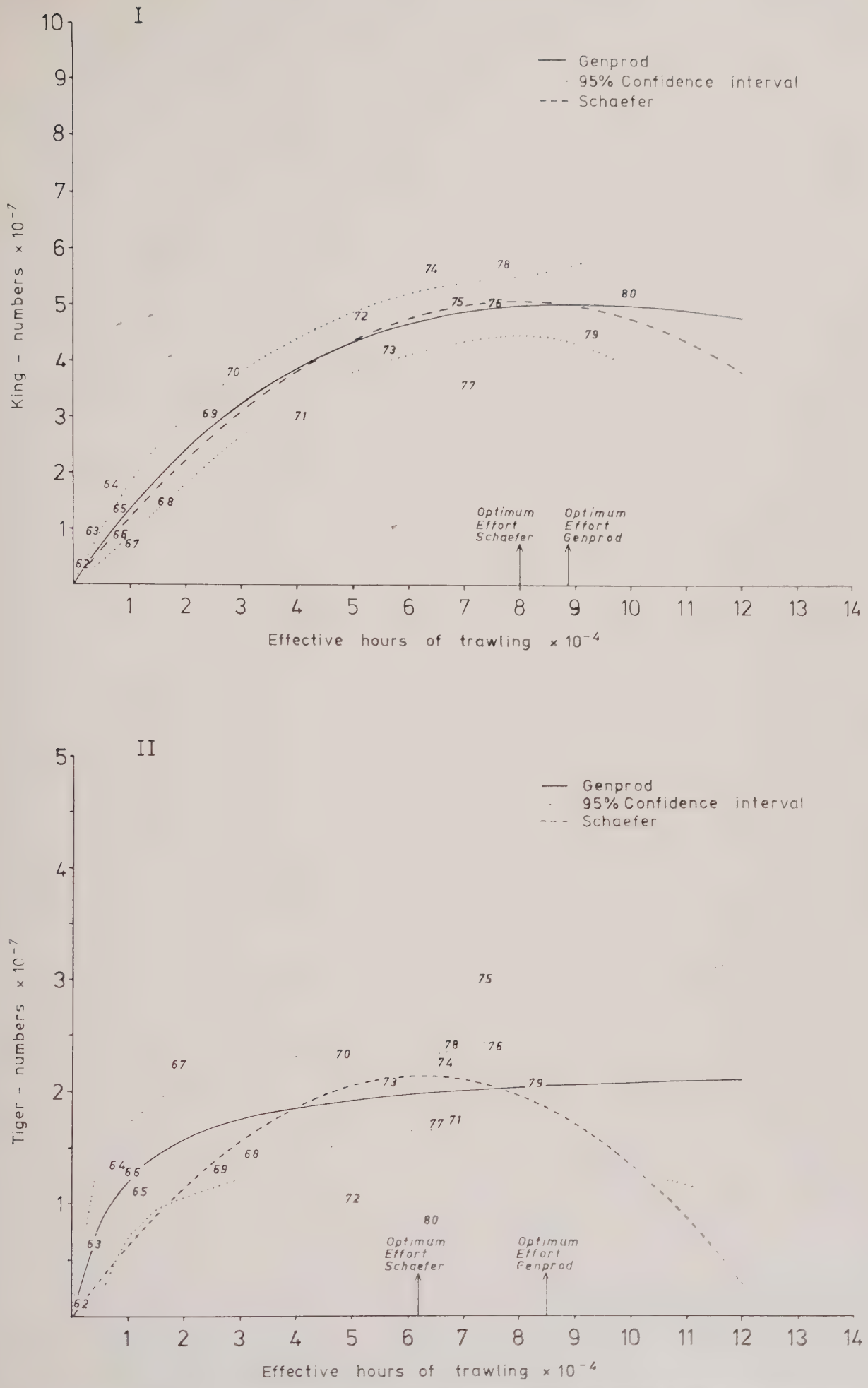

Fig. 4—Relationship between annual catches in numbers of I western king and II brown tiger prawns in Shark Bay 1962–1980 and effective fishing effort. Curves fitted by Genprod, with appropriate 95% confidence limits and by the Schaefer model are shown.

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